

## METHODS AND SYSTEMS FOR GENERATING PROFILE CURVES OF SOLID MODELS

### BACKGROUND OF THE INVENTION

This invention relates generally to generating profile curves and, more particularly, to systems and methods for generating two-dimensional profile curves of three-dimensional solid models.

Geometric models of components are often created with computer  
5 aided design (CAD) programs to enable a user to view a component in a variety of orientations. Often two-dimensional cross-sectional representations of such components are used by various CAD-dependent processes downstream from the CAD program including computer aided engineering (CAE) analysis, computer aided manufacturing (CAM) and drafting. Specifically, with respect to CAE analysis, two-  
10 dimensional CAE analysis often provides results comparable to full three-dimensional analysis, but requires less computational intensity and less time than three-dimensional analysis. Furthermore, with respect to CAM operations, tooling-paths are programmed in two-dimensional planes. Accordingly, two-dimensional tooling-paths include only a maximum revolved profile of the component in a two-dimensional  
15 plane which is simplified in comparison to a profile of the component in a three-dimensional definition.

Known profile curve generators use a plurality of intersecting planes to create two-dimensional representations of three-dimensional solids. The intersecting planes are extended through the three-dimensional solid at a plurality of angles  
20 disposed about an axis of rotation of the three-dimensional solid. Each intersection of the solid produces a set of curves at a given angle relative to the axis of rotation. The different sets of intersecting curves do not create a contiguous profile of the three-dimensional solid, but rather each set of curves is independently rotated into a two-dimensional plane of interest. To graphically represent a full envelope of the three-  
25 dimensional solid, intersecting curves must be extended through the solid at selected

EXPRESS # EL 4770 25631 US - MARCH 22, 2000

angles or potential areas of the solid will not be graphically profiled. Such drafting programs require large amounts of disk storage space to store the numerous intersecting curves. Furthermore, such programs are time-consuming to execute because of the large amount of computations created as a result of the numerous intersections.

## BRIEF SUMMARY OF THE INVENTION

In an exemplary embodiment, a two-dimensional profile curve of a computer representation of a three-dimensional solid model is automatically generated. More specifically, and in one embodiment, a two-dimensional representation is created with a computer executing a profile curve generator without creating separate intersection lines that extend through the three-dimensional solid. The profile curve generator queries the three-dimensional solid to identify faces on the three-dimensional solid. The query of the three-dimensional solid begins after a revolved face is identified as a seed face. The query process continues until all the faces have been queried and processing returns to the seed face. As each revolved face is located, internal edge loops disposed within the face are ignored and a representative curve for the face is created in the two-dimensional plane.

The computer executing the algorithm is programmed to terminate the algorithm if a face edge is not identified which satisfies internal constraints programmed within the algorithm. The computer is also programmed to terminate the execution of the algorithm if the curve generated is not continuous. As a result, the algorithm enables the computer to generate contiguous curves and accurate two-dimensional representations of three-dimensional solids in a more cost-efficient and less time-consuming manner in comparison to known profile curve generators.

## BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a block diagram of a profile curve generator system;

Figure 2 is a flowchart of an algorithm for use with the profile curve generator system shown in Figure 1; and

Figure 3 is a flow chart of an equivalent face curve generator for use with the algorithm shown in Figure 2.

#### DETAILED DESCRIPTION OF THE INVENTION

Figure 1 is block diagram of a profile curve generator system 10 for automatically generating two-dimensional profile curves of three-dimensional solid models. Profile curve generator system 10 includes a server system 12 and a plurality of client systems 14 connected to server system 12. In one embodiment, client system 14 includes a computer (not shown) including a web browser, a central processing unit (CPU), a random access memory (RAM), an output device, for example a monitor, a mass storage device, and an input device, for example a keyboard or a mouse. Server system 12 is accessible to client system 14 via the Internet. Client system 14 is interconnected to the Internet through many interfaces including dial-in-connections, cable modems, special high-speed ISDN lines, and networks, such as local area networks (LANs) or wide area networks (WANs). In one embodiment, client system 14 includes any client system capable of interconnecting to the Internet including a web-based phone or other web-based connectable equipment. Server system 12 is also connected to a mass storage device 18. Mass storage device 18 is accessible by potential users through client system 14.

Figure 2 is a flowchart 80 of an algorithm 82 for use with profile curve generator system 10 (shown in Figure 1). Algorithm 82 is stored in mass storage device 18 (shown in Figure 1) and is accessible to a potential user through client system 14 (shown in Figure 1) to generate a single equivalent profile curve (not shown) for each revolved face (not shown) of a three-dimensional solid (not shown) in a two-dimensional plane (not shown). The three-dimensional solids are introduced to algorithm 82 in an electronic format that is compatible with computer aided design (CAD) type programs. Furthermore, the three-dimensional solids are primarily revolved and have cyclic symmetry about an axis of rotation (not shown). In one embodiment, the three-dimensional models include features (not shown) that are not continuously swept through 360 degrees.

In accordance with algorithm 82, no intersecting planes within the three-dimensional body being sectioned are created. Rather, in lieu of such intersections, a single equivalent profile curve for each revolved face in the two-dimensional plane is created. Initially, a user selects 100 a three-dimensional solid to be profiled and the selection is entered into client system 14. Server system 12  
 5 accesses algorithm 82 from mass storage device 18 and a loop-wise sequence is executed to query 110 the edges of the three-dimensional solid. The loop-wise sequence ensures that a contiguous path of profile curves is created and identifies a circular edge that is a revolved edge. A circular edge that is aligned with respect to  
 10 the three-dimensional solid axis of rotation is considered a revolved edge. Such edges border faces and the three-dimensional solid may include any or all of five different revolved faces including: toroidal, conical, planar, cylindrical, or revolved-spline.

It is then determined 120 if such a circular edge was identified when the loop-wise sequence was executed. Such a circular edge is known as a seed  
 15 revolved edge and is disposed on a seed face. If a circular edge is not identified, an error is reported 122 to the user and algorithm 82 terminates 124. If a circular edge is identified, that specific circular edge is given an identifier "S" and an empty traced list is initialized 130. The traced list identifies which faces of the three-dimensional solid have been processed and traversed. As algorithm 82 is executed, the traced list is  
 20 continuously populated with any faces traversed.

A radius, identified as R1, and an axial position, identified as Z1, of the curved edge S are queried 140. The curved edge S is set 150 to a current edge identifier E1 and a loop 152 is executed. The three-dimensional solid is then queried  
 25 160 to start the execution of loop 152 and to identify a revolved face adjacent current edge E1 that has not been traversed according to the set of faces stored in the traced list.

A determination 170 is made whether an additional face is found. If such a face is found, the face is queried 180 and data from the face (i.e., torus radii, cone angle, etc.) relating to one of the five types of faces, toroidal, conical, planar,  
 30 cylindrical, or revolved-spline, is added 190 to the traced list. As data from the face is

collected and added 190 to the traced list, an external set of edge curves for the face are identified. The external set of edge curves for the face are then cycled 200 to locate a revolved edge, identified as E2, disposed at the furthest radial, identified as R2, and axial location, identified as Z2, from edge E1. A query 210 confirms the  
5 location of the furthest radial, R2, and the axial location Z2.

A subroutine (described in more detail below) is executed to create 220 an equivalent face curve between points (R1, Z1) and (R2, Z2). The equivalent face curve is added 230 to a string of profile curves previously generated. The string of curves are bounding and will eventually define the revolved profile. The computer  
10 executing algorithm 82 is programmed to assume that every face has exactly two circular trimming edges which define the end points, i.e., a beginning and an end, of the equivalent curve, and essentially define the maximum envelope of that particular face.

After the equivalent face curve is added 230 to the string of curves, the  
15 beginning of the next curve to be generated is set 240. To set 240 the beginning of the next curve, algorithm 82 changes the beginning of the next curve to represent the end of the curve just created 220. Additionally, the current edge, E1, is also set to E2 and loop 152 is repeated to query 160 the three-dimensional solid to identify a revolved face adjacent current edge E1 that has not been traversed according to the set of faces  
20 stored in the traced list.

The computer executing algorithm 82 continues executing loop 152 until a determination 170 is reached based on the traced list that the three-dimensional solid includes no additional adjacent resolved faces. If no additional faces are found, the execution of loop 152 ceases, and a determination 300 if the created string of  
25 curves is continuous is made. If the string of curves is continuous, a two-dimensional surface is created 310 and algorithm 82 is terminated 124. If the string of curves is determined 300 non-continuous, the curves are deleted 320 and an error is reported 330 to the user prior to algorithm 82 terminating 124.

Figure 3 is a flow chart of a subroutine 400 for use with algorithm 82 (shown in Figure 2) to create 220 (shown in Figure 2) an equivalent face curve. When algorithm 82 is executed, a query 210 (shown in Figure 2) confirms the location of furthest radial, R2, and the axial location Z2 with respect to edge E1. A subroutine 400 is executed to create 220 an equivalent face curve between points (R1, Z1) and (R2, Z2). After receiving 410 the points (R1, Z1) and (R2, Z2) from loop 152 (shown in Figure 2), a subroutine 400 is executed to determine which of the five types of faces, toroidal, conical, planar, cylindrical, or revolved-spline, is defined between points (R1, Z1) and (R2, Z2) is made. If a face is determined 420 to be toroidal, an arc extending through points (R1, Z1) and (R2, Z2) and including a torus minor radius is created 430. The arc data is introduced to loop 152 to create 220 an equivalent face curve between points (R1, Z1) and (R2, Z2).

If the face is not determined 420 to be toroidal, subroutine 400 is executed to determine 440 if the face is conical, cylindrical, or planar. If the face is conical, cylindrical, or planar, a line extending through points (R1, Z1) and (R2, Z2) and having a slope substantially equal to a slope of the specific face being profiled is created 450. The line data is introduced to loop 152 to create 220 an equivalent face curve between points (R1, Z1) and (R2, Z2).

If the face is not determined to be conical, cylindrical, or planar, subroutine 400 is executed to determine 460 if the face is a spline revolution. If the face is a spline revolution, algorithm 82 extracts 470 the resolved spline, and transforms the resolved spine to a two-dimensional plane. The resolved two-dimensional spline is then trimmed 480 to extend between points (R1, Z1) and (R2, Z2) and the data is introduced to loop 152 to create 220 an equivalent face curve between points (R1, Z1) and (R2, Z2).

The above-described algorithm is cost-effective and highly reliable. The computer executing the algorithm creates a single equivalent profile curve for each revolved face of a three-dimensional solid in a two-dimensional plane without extending intersecting planes through the three-dimensional body being sectioned. Additionally, a detailed and complete representation of the full envelope of the three-

dimensional solid is generated. As a result, an algorithm is provided which when programmed into a computer, permits the computer to produce two-dimensional planar representations of three-dimensional solids in a cost-effective and reliable manner.

5

While the invention has been described in terms of various specific embodiments, those skilled in the art will recognize that the invention can be practiced with modification within the spirit and scope of the claims.